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COAL GASIFICATION SYSTEMS ENGINEERING AND ANALYSIS FINAL REPORT VOLUME I - EXECUTIVE SUMMARY

December 31, 1980

BDM/H-80-800-TR

This Technical Report is submitted to George C. Marshall Space Flight Center under Contract Number NAS8-33824.

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FOREWORD

This executive summary of the final report is submitted to the George C. Marshall Space Flight Center (MSFC), National Aeronautics and Space Administration, by The BDM Corporation, Suite 32, Holiday Office Center, 3322 Memorial Parkway SW, Huntsville, Alabama, 35801, as fulfillment of the final report requirement of Contract Number NAS833824, entitled "Coal Gasification System Engineering and Analysis."

Mr. Thomas Irby is the MSFC Contract Officer Representative. This study is to provide MSFC a basis for their support of the Tennessee Valley Authority Coal Gasification Project, consisting of a four 5,000 ton/day module coal gasification facility. Major project support for this study is provided by the Mittelhauser Corporation acting as a subcontractor.

Dr. Jerry V. Fox is The BDM Corporation program manager. Mr. M. Dale Dowden is the Mittelhauser Corporation project manager.

The task leaders are Dr. J. V. Fox and Dr. W. F. Mackey from The BDM Corporation and Mr. R. S. Bennett, Mr. M. D. Dowden, Mr. T. A. Matchak and Mr. W. H. Seward from the Mittelhauser Corporation.

BDM Corporation technical staff are Dr. R. M. Bass, Mr. C. Carter, Mr. M. F. Funke, Mr. S. Majied, Dr. B. S. Morgan, Mr. J. R. Query and Dr. J. M. Siegel. Mittelhauser Corporation technical staff are Mr. T. A. Atkins, Mr. T. W. Barrs, Mr. W. C. Chambers, Mr. S. E. Heffley, and Mr. S. H. McFeely. Consultants were Mr. M. R. Beychok and Mr. Henry Ho.

The key administration staff contributing to production of the documents are Mrs. D. Blackburn, Mrs. L. Fanning, Mr. K. Kyzer and Ms. E. Roy.

TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

CHAPTER I
INTRODUCTION

The United States, after a number of years of development based on plentiful and inexpensive oil and natural gas, is entering a period of time when it is essential to supplement these energy sources by the increased use of coal. Coal is the nation's most plentiful fossil fuel. Coal gasification is a means of accomplishing this. While utilization of coal through conversion to gaseous products is not new, there is no industry within the U. S. which might serve as a base for establishing cost, operational reliability and requirements, and design data for the large scale environmentally acceptable plans needed.

The Tennessee Valley Authority with systems engineering and analysis support from the George C. Marshall Space Flight Center has initiated a project which would establish the commercial base and demonstrate the requirements for gasifying coal in a large integrated facility. The project consists of gasifying 20,000 tons per day of Eastern coal in a four module plant, the construction of which is staggered to accommodate efficient use of construction manpower and product market development.

As part of its feasibility analysis, TVA has contracted with three engineering firms for conceptual plant designs based on five different gasifiers. These designs will be used to select a gasifier or gasifiers for the plant.

A. PURPOSE

The purpose of study was to support the feasibility analysis and systems engineering studies for a 20,000 tons per day medium Btu (MBG) coal gasification plant to be built by TVA in Northern Alabama. TVA plans to build the plant in four modules of 5,000 tons per day each with the first module on-line in mid-1985. In this study, the BDM Corporation and its subcontractor, the Mittelhauser Corporation, have provided assistance to NASA Marshall Space Flight Center for its feasibility analyses and systems engineering studies in support of the TVA project.

B. OBJECTIVES, ASSUMPTIONS, GUIDELINES AND LIMITING FACTORS

The major objectives of the study were as follows:

(1) Provide design and cost data to support the selection of a gasifier technology and other major plant design parameters

(2) Provide design and cost data to support alternate product evaluation (methane, methanol, gasoline, hydrogen)

(3) Prepare a technology development plan to address areas of high technical risk

(4) Develop schedules, PERT charts, and a work breakdown structure to aid in preliminary project planning.

Assumptions, guidelines and limiting factors are summarized briefly in Figure I.A.1. Detailed guidelines were provided in a TVA publication, "Design Criteria for Conceptual Designs and Assessments of TVA's Coal Gasification Demonstration Plant," March 1980. Other items specified in the TVA document include the following:

(1) Site and transportation conditions

(2) Coal receiving and handling

(3) Building and support structures

(4) Codes and standards

(5) Coal and water characterization

(6) By-product specifications and disposition

(7) Environmental control guidelines

(8) Detailed economic assumptions

(9) Cost power; construction and escalation rates for operations and maintenance labor

C. STUDY APPROACH AND MAJOR RESULTS

The investigative flow and major study results are illustrated in Figure I.A.2. As a baseline for all tasks, the major design-related features of each generic plant system were characterized in a "catalog." A facility requirements document providing plant specifications for design guidance was

Location: Murphy Hill, Alabama

Coal: Kentucky No. 9

Coal cost: $1.25/mm Btu; 1/1/80 dollars

Product Gas:

Pressure:	600 psig minimum
Temperature:	120 degrees F maximum
Higher Heating Value:	285 Btu/SCF minimum
Total Sulfur:	200 ppm maximum
Total Moisture:	7 lbm/MMSCF maximum
Chemical Composition:	Within the constraints described above, the composition of the gas at the plant fence may be established solely by the coal gasification and gas cleanup processes.

Design Capacity: 20,000 tons of coal per day, in four modules of 5000 tons per day each

On stream Factor: 90 percent

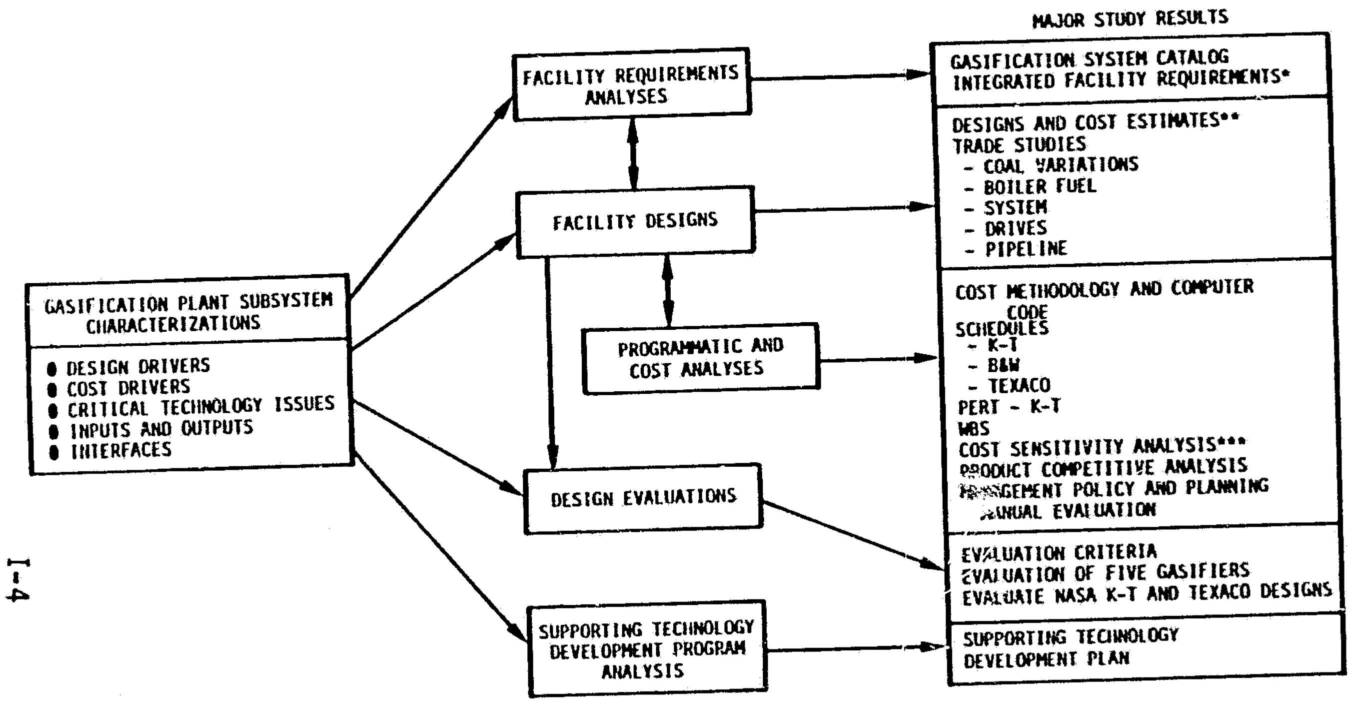
Module life: 20 years after startup

Initial Operation Schedule:

First module	6/1/85
Second module	6/1/86
Third module	1/1/87
Fourth module	6/1/87

Candidate Gasifiers:
- Koppers-Totzek
- Texaco
- Babcock and Wilcox
- Lurgi
- BGC/Lurgi

FIGURE I.A.1. MAJOR GASIFICATION PLANT PARAMETERS



** DESIGNS AND COST ESTIMATES

MBG:

K-T
TEXACO
B&W
LURGI
SLAGGING LURGI

ALTERNATE PRODUCTS
KT
- METHANE
- METHANOL
- GASOLINE
- HYDROGEN

TEXACO
- METHANE
- METHANOL
- GASOLINE
- HYDROGEN

K-T - MIXED MBG AND METHANE

K-T AND TEXACO -
MIXED MBG AND METHANE

LURGI - METHANE
LURGI - METHANOL

*** COST SENSITIVITY ANALYSIS

K-T - MBG

FOR:
COAL COST
CAPITAL COST
OPERATING COST
SERVICE FACTOR
BYPRODUCT VALUE
CONSTRUCTION PERIOD
OPERATING LIFE
GAS PURITY
GAS PRESSURE
DISCOUNT RATE

* DEVELOPED JOINTLY WITH NASA

FIGURE I.A.2. PROGRAM ORGANIZATION

developed jointly with NASA. Based on the catalog and requirements data, approximately 17 designs and cost estimates were developed for MBG and alternate products. Additionally, a series of generic trade studies was conducted to support all of the design studies.

To supplement the designs, a set of cost and programmatic analyses were conducted. The cost methodology employed for the design and sensitivity studies was documented and implemented to a computer program. Plant design and construction schedules were developed for the K-T, Texaco and B&W MBG plant designs. A generic work breakdown structure was prepared, based on the K-T design, to coincide with TVA's planned management approach. An extensive set of cost sensitivity analyses were completed for the K-T, Texaco and B&W design. Product price competitiveness was evaluated for MBG and the alternate products. Finally, a draft Management Policy and Procedures Manual developed by TVA was evaluated and modifications were recommended.

Several evaluation tasks were conducted. Evaluation criteria were developed for assessing the preliminary gasifier designs prepared for TVA by three engineering firms. An evaluation of the advantages and disadvantages of the five candidate gasifiers was prepared. Finally, NASA's own K-T and Texaco designs were compared to the BDM/Mittelhauser designs.

A supporting technology development plan was developed to address high technology risk issues. The issues were identified and ranked in terms of importance and traceability, and a plan developed for obtaining data or developing technology required to mitigate the risk.

In reading this summary, it should be noted that the systems described in Chapter II.A are from the systems survey task. Specific systems for this study's results are in Chapter II.B.

D. ORGANIZATION OF THIS REPORT

Each of the major study results listed in Section C is described in Volume II of this report. The following outlines the report by chapters.

(1) Chapter I Introduction
(2) Chapter II Gasification System Characterizations
(3) Chapter III MBG Facility Designs
(4) Chapter IV Trade Studies
(5) Chapter V Cost Analyses and Methodology
(6) Chapter VI Alternate Product Designs
(7) Chapter VII Schedule and Network Analysis
(8) Chapter VIII Product Competitive Evaluations
(9) Chapter IX Work Breakdown Structure
(10) Chapter X Management Policies and Procedures
(11) Chapter XI Commercial Design Assessment
(12) Chapter XII Assessment of Critical Technology Needs

In addition, complete results of each of the project tasks are included as Appendices A through H.

(1) Appendix A Coal Gasification System Catalog
(2) Appendix B Medium Btu Gas Design
(3) Appendix C Alternate Product Designs
(4) Appendix D Costs and Economic Studies
(5) Appendix E Methodology of Cost Determination
(6) Appendix F Critical Technology Evaluation and Recommendations
(7) Appendix G Commercial Design and Technology Evaluation
(8) Appendix H Work Breakdown Structure

CHAPTER II
SUMMARY OF FINDINGS

A. GASIFICATION SYSTEM CHARACTERIZATIONS

1. Description of Gasifier Technologies

a. Introduction

TVA selected five gasification technologies for evaluation: Koppers-Totzek, Texaco, Lurgi Dry Ash, Slagging Lurgi, and Babcock and Wilcox. Each of these is described below. The Unit Operations referenced in these descriptions are discussed in Section D below and in Appendix A.

This section briefly describes the gasification technologies, major design and cost considerations, and the other system in the gasification plant. These topics are treated in more detail in Appendix A.

b. Koppers-Totzek

The Koppers-Totzek gasifier is a high temperature, cocurrent entrained flow gasifier which accepts coal from Coal Preparation along with oxygen and steam to produce intermediate BTU gas. It is a proprietary unit licensed by Krupp-Koppers of Germany. Sized coal enters the pretreatment area of Gasification, where it is crushed, ground, and dried. It is then fed to eight screw conveyors that feed four pairs of burners. Oxygen and steam carry the coal through the burners into the gasifier.

The oxygen, steam, and coal react to gasify the carbon and volatile matter of the coal and to convert the coal ash into molten slag. The gas exiting each gasifier is direct water quenched to below the ash fusion temperature, in order to solidify entrained slag droplets. The remaining slag forms a layer on the refractory walls and flows down through a separate chute into quench tanks.

After the gas is quenched, gas and entrained ash particles pass through a waste heat boiler where the gas is cooled to approxi-

mately 350^{o} by raising high pressure steam. The gas is then scrubbed for particulate removal. The clean intermediate BTU product gas is then further cooled before going to Acid Gas Removal.

With the K-T gasifier, as with all high temperature entrained flow gasifier, no tars, phenols, oils, etc., are produced so the gas requires less cleanup than those systems that produce hydrocarbons. Because of the high operating temperatures the gasifer requires an appreciable amount of oxygen per pound of coal fed. The higher heating value of the dry gas produced from the K-T gasifier is in the range of 285-300 BTU/SCF. The Koppers-Totzek gasifier typically operates at a pressure of about 7 psig. Maximum temperatures can run as high as 3300^{o}F.

c. Texaco

The Texaco Coal Gasification Process uses a coal slurry feed, consisting of fresh ground coal together with recycled fine slag and carbon with a total solids content 50 to 65% by weight. The slurry is pumped from mix tanks in the grinding and slurry section to the gasifier slurry tank. A circulating pump circulates the slurry through this tank and supplies slurry to the suction of the high pressure charge pump.

The coal-water slurry is fed through a specially developed burner into a refractory-lined gasifier reactor. Partial combustion with oxygen takes place at a pressure of 600 psig, or higher, and a temperature in the range of 2300 to 2800^{o}F to produce a gas consisting mainly of CO, H_2, CO_2, and steam. Most of the sulfur in the coal is converted to H_2S, and the balance converts to COS. Nitrogen and argon from the oxygen feed appear in the gas together with most of the nitrogen from the coal. The gas contains a small amount of methane, some unconverted carbon and all of the ash in the form of slag. The gas is essentially free of uncombined oxygen.

The upper section of the gasifier is the refractory-lined chamber in which the partial oxidation reaction takes place. In many conceptual designs, part of the gas is withdrawn and cooled to below the

ash fusion point by mixing with cooled recycle gas. Entrained slag particles, solidified by cooling, are then removed from the gas. The gas is then cooled by raising high-pressure steam in a specially-designed waste heat boiler. The gas then passes to the Gas Cooling System. To date, these high-pressure steam generators have not been commercially proven in coal gasification service.

At least a portion of the gas from the gas generator reaction section passes straight down into the quench section of the gasifier. This stream carries the bulk of the larger particles of slag, and it is immediately quenched with water from the 2300 to 2800^{O}F range to about 400^{O}F. The gas from the generator quench chamber joins the main stream of gas going to the gas cooling operation.

d. Lurgi

The Lurgi gasifier, dry ash, gravitating bed type, is commercially available from Lurgi Kohle and Mineraloeltechnik. The gasifier is a water jacketed pressurized unit comprised of a series of vertically stacked vessels. There are, from top to bottom, a coal hopper, coal lock, water jacketed gasifier, ash lock, and ash quench chamber.

Coal is conveyed from Coal Preparation to the coal hopper from which it is fed by gravity to the depressurized coal lock through a hydraulically operated valve. The lock is then isolated and pressurized with a slipstream of inert gas (mainly N_2) and the coal is transferred to the gasifier through another hydraulically operated valve.

The coal flowing down through the gas produced represents a slowly moving bed which has several distinct zones. In the first zone at the top of the gasifier, coal is preheated and dried by contact with the hot crude gas leaving the reactor. As the coal moves down and is heated further, devolatilization occurs and gasification commences. The bottom of the bed is a combustion zone where carbon reacts with oxygen to form CO and CO_2. The oxidation provides the overall heat for the gasification and devolatilization reactions which are endothermic. Only a negligible amount of unburned carbon remains in the ash.

When MBG is to be made, oxygen from Air Separation and Oxidant Feeding, and steam enter the gasifier near the bottom and are heated as they rise upward to the combustion zone by the hot ash moving down from the combustion zone. Oxygen flow rate is controlled to accomplish complete gasification of coal. Steam rate is controlled to maintain a specified gasifier bottom temperature to prevent melting or clinkering of the ash.

A portion of the gasifier process steam is generated at about the operating process of the gasifier, in the gasifier jacket. The balance is provided through waste heat recovery or from Steam Generation.

The crude gas leaving the gasifier contains appreciable quantities of tars, oils, naptha, phenols, fatty acids, ammonia, hydrogen sulfide, sulfur compounds, and a small amount of coal and ash dust. The crude gasifier effluent temperature ranges from 575^{o}F to over 1000^{o}F. The effluent flows through a scrubbing cooler where it is washed with a stream of process condensate. The washing process quenches the gas to about 350-400^{o}F and condenses the high boiling tar fractions. Coal and ash dust are removed with the condensed tar leaving the quenched effluent gas essentially free of particulate matters.

Ash from the process is continuously collected by a rotating ash grate and moved to the ash lock hopper. Ash collected in the lock is depressurized and discharged batchwise to an ash quench chamber where it is cooled in water. The ash lock is pressurized with steam.

e. Babcock and Wilcox

The Babcock and Wilcox gasifier is a high temperature, cocurrent entrained flow gasifier which accepts coal from Coal Preparation along with oxygen and steam to produce medium BTU gas. It is a proprietary unit licensed by Babcock and Wilcox.

Sized coal enters the pretreatment area of Gasification, where it is pulverized and tangentially injected through two rows of water cooled nozzles into the gasifier. Both the coal and char are fired with oxygen from Air Separation. The coal and char are partially

combusted to form a hot reducing gas. At the high temperatures present in the gasifier, the ash in the coal and tar becomes molten and continuously flows down the walls of the gasifier.

In the gasification section, there is an inner shell of water cooled tubes (water wall) where saturated steam is produced.

The gas exits the gasifier proper at about 1800^{O}F and enters the waste heat boiler section where it is cooled to 700^{O}F. From the waste heat boilers, the gas enters a cyclone where 90-95% of the carryover ash and char is removed. This char and ash stream is injected back into the gasifier. The 700^{O}F gas is further cooled and cleaned in Gas Cooling before going to Acid Gas Removal.

f. BGC/Lurgi

The BGC/Lurgi coal gasification system, sometimes known as slagging Lurgi, consists of coal and flux feed, gasification, raw gas treating, and slag handling.

The design of the slagging Lurgi gasifier is based on proprietary technology held by Lurgi Kohle Mineraloeltechnik and the British Gas Corporation. It is similar to the dry-ash Lurgi gasifier described earlier, except that in the bottom of the gasifier the coal ash melts as a eutectic with added flux to form slag. Flux is added to the coal feed to produce a lower melting eutectic with the coal ash. The molten slag collects at the bottom and is removed intermittently from the gasifier through a slag tap hole.

The coal and flux, entering the top of the Gasifier, descends in a moving bed in countercurrent flow to steam, oxygen and produced gas. While traveling from the top to the bottom of the gasifier, the coal is dried, devolatilized, and gasified. The heat required for these three steps is supplied by the exothermic reaction between the carbon in the coal and the oxygen in the bottom of the gasifier.

As the produced gas passes through the coal bed, its final composition is determined by the following:

- Exothermic and endothermic reactions occurring simultaneously in the gasification zone.
- Formation of hydrocarbons, phenols, fatty acids, and minor organic compounds in the devolatilization zone.
- Evaporation of coal moisture in the drying zone.

Raw gas from the BGC/Lurgi gasifier is treated similarly to that from a dry-ash Lurgi gasifier, as described earlier.

After the coal ash melts as a eutectic with the added flux to form slag, the molten slag collects at the bottom of the gasifier and is tapped intermittently through a tap hole into the Quench Vessel.

2. Gasification Facility Systems

The coal gasification facility comprises about 25 major systems or types of unit operations, listed in Figure II.A.1.

The systems employed, the nature of their interconnections, and stream characteristics depend on the gasifier technology and the specific plant design. A representative example of a system configuration for the Lurgi gasifier with major streams identified, is shown in Figure II.A.2. This configuration is shown because it contains more of the systems listed in Figure II.A.1 than the other gasifiers. A detailed description of all typical stream components, pressure, and temperatures ranges is provided in Appendix A. Detailed flow sheets and stream characteristics are provided in Appendix B.

3. Design and Cost Drivers

Major design and cost drivers, developed for each major plant system, are presented in detail in Appendix A. Design drivers are the

COAL RECEIVING, STORAGE AND TRANSFER
COAL PREPARATION AND FEEDING
GASIFICATION
GAS COOLING
ACID GAS REMOVAL
COMPRESSION
SOLIDS TREATMENT SYSTEM
TAR-OIL SEPARATION
PROCESS CONDENSATE TREATMENT
PHENOL RECOVERY
AMMONIA RECOVERY
SULFUR RECOVERY
BIOLOGICAL TREATMENT
COOLING WATER SYSTEM
INCINERATION
AIR SEPARATION AND OXIDANT FEEDING
FINAL SOLIDS DISPOSAL
BY-PRODUCT STORAGE AND LOADING
SULFUR STORAGE AND LOADING
STEAM GENERATION
RAW WATER TREATMENT
FLUE GAS TREATMENT
PLANT ELECTRICAL SYSTEM
BUILDINGS AND SUPPORT FACILITIES
CONTROL AND INSTRUMENTATION

Figure II.A.1. Unit Operation Categories

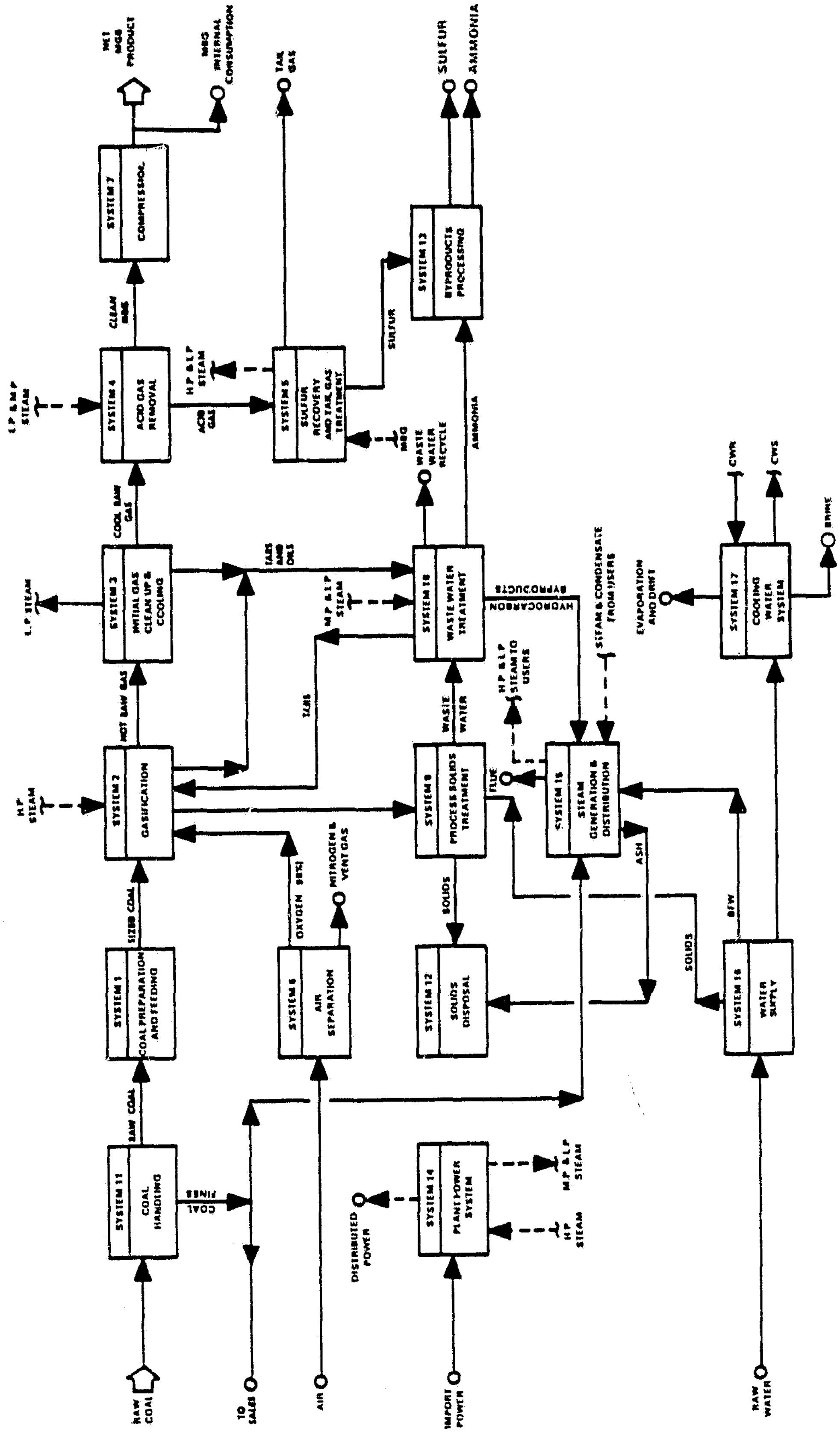


Figure II.A.2. Block Flow Diagram for Lurgi MBG Module

specifications or other considerations that are major determinants of the resulting design. Cost drivers are the major determinants of product cost.

For the plant as a whole, the major design drivers are plant capacity; coal characteristics (carbon, hydrogen, sulfur, trace elements, moisture); product specifications (type of products, pressure, sulfur level); and waste water effluent restrictions. Plant capacity establishes the scale for the design, and will have a major impact on solids handling, utility scaling, train configurations, and sparing. The coal characteristics will affect the choice of gasifier and will drive design of all cleanup systems. Product specification will determine requirements for compression and sulfur removal. If the product is not MBG, product specifications may affect the choice of gasifier and will determine downstream processing requirements. Water effluent specifications will have a major impact on design of the complex waste treatment systems.

The major cost drivers are capacity, coal characteristics, product specifications, and coal cost. The capacity will determine the applicable scale economies. Coal characteristics and product specifications will determine the product yield and selection of major capital items (gasifier, gas cleanup, compression, conversion). The coal cost is a major operating cost independent variable, while labor and spare parts are determined primarily by capital costs.

B. MBG FACILITIES

1. Summary of Designs

A total of five designs for producing MBG were completed for this study. Koppers-Totzek, Texaco, and B&W Reference Facility Designs were arrived at by conducting trade studies based on preliminary definition design configuration which led to the selection of specific processes to match the requirements of the various systems. Lurgi and BGC/Lurgi designs were stopped at the definition level. However, results of the trade studies con-

ducted earlier were incorporated as appropriate. Each plant was designed around the general modular configuration shown in Figure II.B.1. Tables II.B.1 and II.B.2 list the system requirements and their status. Each plant is based on 20,000 TPD of Kentucky No. 9 coal being gasified in four modules of 5,000 TPD each. Each design is based on zero waste water discharge. Product delivery is at 600 psig and at least 285 Btu/scf. In all designs, solid waste are stored on-site in a lined pit. Tables II.B.3 and II.B.4 contain the results of all five designs.

a. Koppers-Totzek Based Plant

In each module, coal is pulverized and then gasified in eight parallel gasification trains. A ninth gasifier is held in reserve.

The cooled raw gas is compressed and fed to a Selexol acid gas removal system. Excess gasifier jacket steam, waste heat boiler steam and other process-derived steam is used to satisfy process steam requirements first and to drive turbines in the air separation and compression systems second. Additional power requirements are met with purchased electricity. Two parallel oxygen trains per module are used. The first module has two Claus plus Beavon-Stretford sulfur plants; the other three have only one.

b. Texaco Based Plant

In each module, coal is pulverized, slurried, and then gasified in three parallel Texaco coal gasification trains. A fourth train is held in reserve. Due to a lack of a proven waste heat boiler for this process, the study is based on quenching the entire raw gas stream to 450°F within the reactor. This process operates at sufficiently high pressure to meet plant requirements without additional compression. After being cooled to about 100°F, the gas is processed in a Selexol unit and dried to meet pipeline specifications. Three air separation trains are put in Modules 1 and 3. Two trains are put in Modules 2 and 4 with intermodule sharing.

c. Babcock and Wilcox Based Plant

In each module, coal is pulverized and lock hoppered into two parallel B&W coal gasification reactors. A third reactor is held in reserve. The B&W reactors produce large quantities of high pressure steam in steam

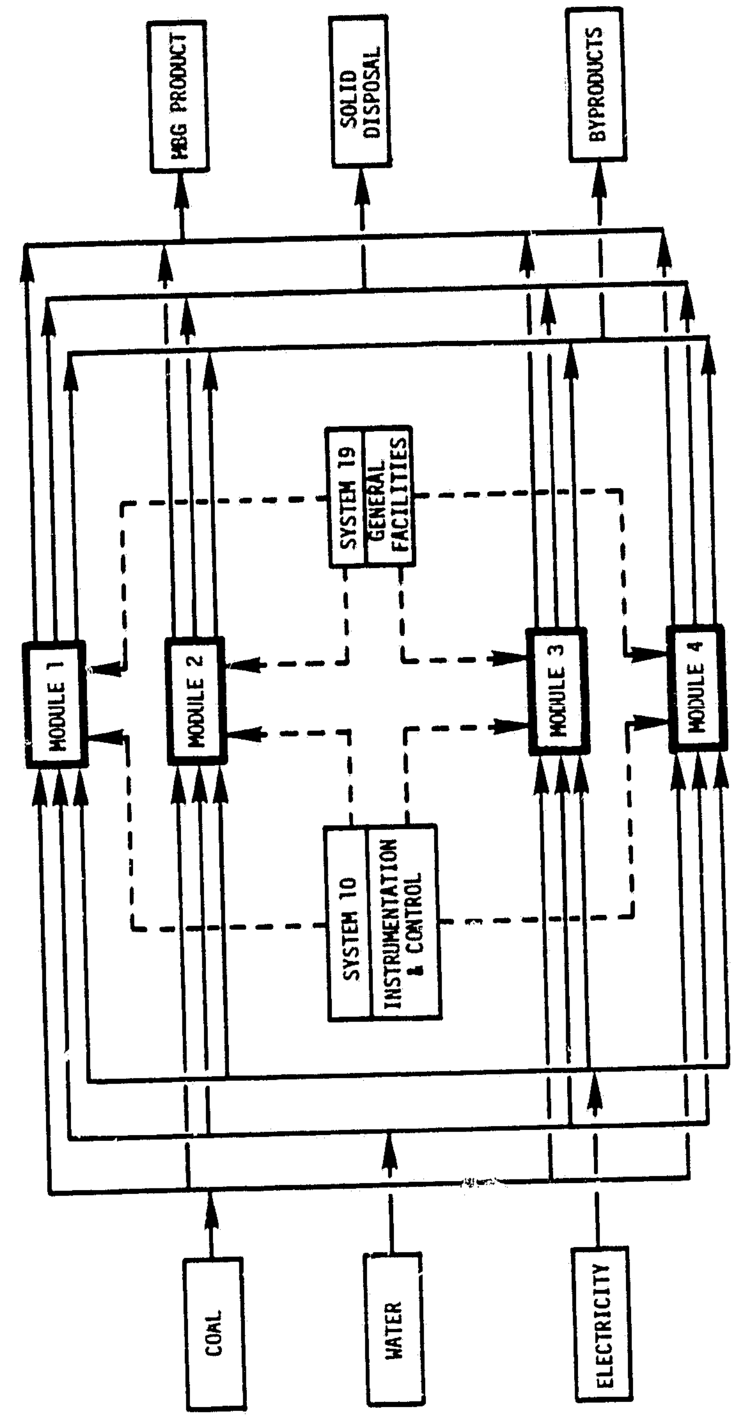


Figure II.B.1. Plant Module Configuration

TABLE II.B.1. PLANT SYSTEMS SUMMARY

SYSTEM NO.	SYSTEM DESCRIPTION	KT NUMBER OF PER MODULE	KT COST UNITS PER FACILITY	TEXACO NUMBER OF PER MODULE	TEXACO COST UNITS PER FACILITY	B&W NUMBER OF PER MODULE	B&W COST UNITS PER FACILITY	LURGI NUMBER OF PER MODULE	LURGI COST UNITS PER FACILITY	BGC/LURGI NUMBER OF PER MODULE	BGC/LURGI COST UNITS PER FACILITY
1	COAL PREPARATION & FEEDING	1	4	1	4	3	12	1	4	1	4
2	GASIFICATION	9	36	4	16	3	12	7	28	3	12
3	INITIAL GAS CLEANUP & COOLING	1	4	1	4	3	12	1	4	1	4
4	ACID GAS REMOVAL	1	4	1	4	1	4	1	4	1	4
5	SURFUR RECOVERY	1	5	1	5	1	5	1	5	1	5
6	AIR SEPARATION	2	8	2 or 3	10	2	8	1	5	1	5
7	COMPRESSION	1	4	1	4	1	4	1	4	1	4
8	PROCESS SOLIDS TREATMENT	1	4	-	1	1	4	1	4	1	4
10	INSTRUMENTATION & CONTROL	-	4	-	1	-	1	-	1	-	1
11	COAL HANDLING	-	1	-	1	-	1	-	1	-	1
12	SOLIDS DISPOSAL	-	1	1	4	-	4	-	1	-	1
13	BY-PRODUCT PROCESSING	1	4	1	4	1	4	1	4	1	4
14	PLANT POWER SYSTEM	-	4	1	4	1	4	1	4	1	4
15	STEAM GENERATION/DISTRIBUTION	1	4	1	4	1	4	2	8	2	8
16	RAW WATER MAKEUP	1	4	1	4	1	4	1	4	1	4
17	COOLING WATER SYSTEM	1	4	1	4	1	4	1	4	1	4
18	WASTE WATER TREATMENT	1	4	1	4	1	4	1	4	1	4
19	GENERAL FACILITIES	1	1	-	1	-	1	-	1	-	1

TABLE II.B.2. SYSTEM TECHNOLOGY ASSESSMENT

SYSTEM		K-T	TEXACO	B&W	LURGI	BGC-SLAGGER
1	COAL PREPARATION & FEEDING	CP	CA	CA	CP	CP
2	GASIFICATION	CP	RD	RD	CP	RD
3	INITIAL GAS CLEANUP & COOLING	CP	CA/CP	CA/RD	CP	CP
4	ACID GAS REMOVAL	CA	CA	CA	CA	CA
5	SULFUR RECOVERY & TAIL GAS TREATMENT	CA	CA	CA	CA	CA
6	AIR SEPARATION	CP	CP	CP	CP	CP
7	COMPRESSION	CP	-	-	CP	CP
8	PROCESS SOLIDS TREATMENT	CP	CP	CP	CP	CP
9	INCINERATOR	-	-	-	-	-
10	INSTRUMENTATION & CONTROL	CP	CP	CP	CP	CP
11	COAL HANDLING	CP	CP	CP	CP	CP
12	SOLIDS WASTE RECYCLING/DISPOSAL	CP	CP	CP	CP	CP
13	BYPRODUCT PROCESSING	CP	CP	CP	CP/CA	CP/CA
14	PLANT POWER SYSTEM	CP	CP	CP	CP	CP
15	STEAM GENERATION/DISTRIBUTION	CP	CP	CP	CP/CA	CP/CA
16	WATER SUPPLY	CP	CP	CP	CP	CP
17	COOLING WATER SYSTEM	CP	CP	CP	CP	CP
18	WASTE WATER TREATMENT	CA	CA	CA	CA/RD	CA/RD
19	GENERAL FACILITIES	-	-	-	-	-

KEY: CP = COMMERCIALLY PROVEN, CA = COMMERCIALLY AVAILABLE, RD = READY FOR DEMONSTRATION

TABLE II.B.3. MBG FACILITY RESULT SUMMARY

PROCESS	KT	TEXACO	B&W	LURGI	BGC/LURGI
NET YIELD (MMSCFD)	900	1,080	976	1,160	959
GAS HHV (BTU/SCF)	300	291	303	308	384
COMPOSITION (VOL. %)					
HYDROGEN	29.6	37.2	30.7	46.8	28.9
NITROGEN	1.5	1.3	3.4	0.4	0.5
CARBON MONOXIDE	63.5	51.2	63.3	17.2	59.6
CARBON DIOXIDE	4.9	9.8	2.6	26.1	1.8
METHANE	0.5	0.5	-	9.0	8.7
ETHANE +	-	-	-	0.4	0.4
(PPM WT.)					
HYDROGEN SULFIDE	62	66	10	101	134
CARBONYL SULFIDE	461	489	58	498	369
WATER	125	102	127	140	134

TABLE II.B.4. DESIGN STUDY RESULTS SUMMARY

		KOPPERS-TOTZEK	TEXACO	B&W	LURGI***	BGC/LURGI***
FEED COAL -	TPY	6,570,000	6,570,000	6,570,000	10,000,000	10,000,000
COAL FINES SOLD		-	-	-	530,000	3,017,000
WATER -	GPM	12,800	10,132	11,112		
PURCHASED ELECTRICITY -	MM KWHY	3,720	1,560	183		
MBG PRODUCT -	M MCFD	898	1,278	976	1,160	960
MBG PRODUCT -	MM MSCFY	295	354	322	381	315
MBG QUALITY -	BTU/SCF	305	291	303	308	384
SULFUR PRODUCT (PRILLED)-	LTPD	668	668	673	580	590
SULFUR PRODUCT	LTPY	220,000	220,000	222,000	191,000	194,000
TOTAL CAPITAL REQMTS. -	MM	$2,371	$2,091	$3,347(2,567)**	$2,746	$2,061
OPERATING & MAINTENANCE - COSTS	MM/YR	$ 189	$ 129	$ 138	$ 134	$ 100
COAL, CATALYST, CHEMICALS-	MM/YR	$ 181	$ 181	$ 181	$ 279	$ 276
By-PRODUCT CREDIT -	MM/YR	-	-	-	$ 47	$ 66
PLANT OPERATING STAFF		346 PERSONS	271 PERSONS	271 PERSONS		

*COSTS ARE IN 1980 DOLLARS.
**BASED ON INSTALLATION FACTOR OF 2.31 AND 1.5.
***RESULTS BASED ON LOWER LEVEL OF EFFORT.

coils within the reactor refractory and in bare coils above the refractory. Thus, the quantity of purchased electricity is relatively low for this design. Gas from the reactors at 275 psig is cooled, compressed and treated in a Selexol and gas removal system. Sulfur is recovered in a Claus plus Beavon-Stretford unit. The plant contains two trains in Module 1 and one train in Modules 2 through 4. Two trains of air separation are included in each module.

d. Lurgi Based Plant

In each module, coal is ground, sized and lock hoppered into six Lurgi coal gasification reactors. A seventh reactor is held in reserve. Coal fines are recovered and used to supplement tars and oils as boiler fuel to supply the plant process steam requirements. Excess fines are sold as a plant by-product. Phenolic compounds are recovered in a Phenosolvan unit and burned along with by-product tar. Ammonia is recovered from sour water with a Phosam-W process unit. Raw gas leaves the reactor at 650°F and 450 psig and is further cooled in a Lurgi cooling unit to 100°F. The Selexol acid gas removal system removes hydrogen sulfide and carbon dioxide prior to compression. The sweet gas is compressed and dried to meet the 600 psig plant specification. Sulfur is recovered in a Claus/Beavon-Stretford unit with two trains in Module 1 and one train in each of the following modules. This design is the only one of the five that discharges dry ash from the reactor.

e. BGC/Lurgi Based Plant

In each module, coal is ground, sized and lock hoppered into two BGC/Lurgi reactors. A third reactor is held in reserve. Coal fines are recovered and used to supplement tar and oil for raising steam. Excess fines are sold as a plant by-product. Phenolic compounds are recovered with a Phenosolvan unit and used as fuel. Ammonia is recovered in a Phosam-W unit and sold as a by-product. Flux is added to the coal feed to lower the ash melting point so as to facilitate molten slag withdrawal from the bottom of the reactor. Raw gas from the reactor is cooled to 100°F. Waste water with tar and oil is sent to waste water treating for tar, oil, phenol, and ammonia recovery. Cool gas is compressed and dried for pipeline delivery.

2. MBG Facility Cost Summary

The cost of the five gasification processes analyzed in this study are compared in Table II.B.5. The BGC-Lurgi process is the most cost-effective with a product price of $4.31/MMBTU (constant 1980 dollars). The next most cost-effective system is Texaco, with a product price of $5.00. The least cost-effective process is Koppers-Totzek, with a product price of $6.64, 54 percent greater than the values for BGC-Lurgi. Table II.B.6 lists the processes in order of cost-effectiveness and shows the product prices normalized to BGC-Lurgi.

The BGC-Lurgi process is lowest cost in both capital requirement and total O&M. The entries in Table II.B.2.1 show that BGC-Lurgi total facility investment (instant plant value) $1,387,000,000, and total capital requirements, $2,061,000,000, are the lowest of all the processes. Total O&M, feedstock, catalysts and chemicals are $310,000,000 annually. Texaco, the second most cost-effective system, is almost identical in both capital and total O&M costs, but is significantly lower in annual product, producing 103 x 10^{12} BTU compared to 121 x 10^{12} BTU for BGC-Lurgi. This difference accounts for the 16 percent advantage of the BGC-Lurgi product price.

BGC-Lurgi has a low total O&M annual cost despite high feedstock, catalysts and chemical cost. The latter are $276,000,000 per year compared to Texaco, Koppers-Totzek, Babcock and Wilcox identical values of $181,000,000 per year. The higher BGC-Lurgi feedstock, catalyst, and chemical costs are offset by (1) a low O&M annual cost of $100,000,000 and (2) annual byproduct credits of $66,000,000.

The Lurgi process ranks third* in cost-effectiveness behind BGC-Lurgi and Texaco. This is due primarily to a significant difference in capital costs between BGC-Lurgi and Lurgi. The major contributors to the high cost of the Lurgi process are the wastewater treatment system, which is more than double the BGC-Lurgi, and steam generation, and distribution, which is two-thirds greater for Lurgi than for BGC-Lurgi.

TABLE II.B.5. COST COMPARISON OF GASIFICATION PROCESSES
(Millions of dollars, unless otherwise noted)

Cost Category / Process	Texaco	Koppers-Totzek	Babcock & Wilcox	BGC-Lurgi	Lurgi
Total Facility Investment (Instant Plant)	1,416	1,591	2,437	1,387	1,879
Total Capital Requirements	2,091	2,371	3,347	2,061	2,747
O&M, Feedstock, Catalyst and Chemicals *	310	370	319	310	366
Feedstock, catalyst and Chemicals	181	181	181	276	279
O&M	129	189	138	100	134
Byproduct credits	0	0	0	(66)	(47)
Annual Product (10^{12} BTU)	103	90	100	121	117
UAE Cost of Service Price (Current $/MM BTU)	$13.38	$17.79	$17.11 (14.37)**	$11.54	$14.56
Product Price (Constant 1980 $/MM BTU)	5.00	6.64	6.39 (5.37)**	4.31	5.44

*Total facility and 90% service factor.
**Based on installation factors of 2.31 and 1.5, respectively.

TABLE II.B.6. RANKING OF GASIFICATION PROCESSES BY COST-EFFECTIVENESS

Gasification Process	Normalized Product Price
BGC-Lurgi	1.00
Texaco	1.16
Lurgi	1.26
Babcock & Wilcox	1.48 (1.24)
Koppers-Totzek	1.54

The Babcock and Wilcox process is the most costly, due to a high gasification system cost.*

*Two cases are considered in the cost analysis of the B&W-based plant. In the first case, base equipment cost for System 2, Gasification, is multiplied by an installation factor of 2.31 to arrive at the installed cost. This factor was arrived at by back calculation from a more detailed cost analysis based on Koppers-Totzek technology as shown in Appendix D. In the second case, an installed equipment cost factor of 1.5 was used based on information from B&W and supplied to this study by NASA. In this report, the first case result is used followed by the second case result in parenthesis. It is noted that discussions presented in Chapter XI imply that higher capacity units such as B&W should have a lower installation factor than low capacity units.

The higher product price for Koppers-Totzek is driven by a combination of the highest total O&M annual costs, $370,000,000, and the lowest efficiency, with an annual product of 90 x 10^{12} BTU.

Detailed cost data for each process are found in Appendix D.

C. SUMMARY OF TRADE STUDIES AND COST SENSITIVITY ANALYSIS

1. Trade Studies

A number of trade studies were performed in the course of arriving at the final designs presented here. These are listed along with their respective results in Table II.C.1.

It is noted that except for the consideration of deep cleaned coal, none of the trade options affected the final price as much as five percent.

TABLE II.C.1. TRADE STUDY SUMMARY

UNIT OPERATION	TYPE	ALTERNATIVES
COAL RECEIVING & STORAGE	CONFIGURATION	*• 4 x 5000 TPD MODULAR SYSTEMS • 1 x 20,000 TPD MODULAR SYSTEMS
COAL PREPARATION & FEED (TEXACO)	SELECTION	• DRY FEEDING *• SLURRY FEEDING
ACID GAS REMOVAL	SELECTION	*• SELEXOL • RECTISOL • BENFIELD • SULFINOL • STRETFORD
GAS COMPRESSION	CONFIGURATION	*• AGR AFTER COMPRESSION • AGR BEFORE COMPRESSION • AGR BETWEEN COMPRESSION STAGES
BY-PRODUCT STORAGE & LOADING (LURGI & BGC)	TAR/OIL DISPOSITION	*• BURN-IN FIRED EQUIPMENT • SELL AS BY-PRODUCT
PHENOL RECOVERY	SELECTION	• NON-RECOVERY *• PHENOSOLVAN • CHEM-PRO
NH_3 RECOVERY	SELECTION	• NON-RECOVERY • CHEVRON-WWT *• PHOSAM-W
SULFUR RECOVERY	SELECTION	• CLAUS + SCOT *• CLAUS + BEAVON • CLAUS + WELLMAN-LORD
STEAM GENERATION	BOILER SELECTION	*• MAXIMIZE PURCHASED POWER, NO BOILERS EXCEPT STARTUP BOILER • COAL-FIRED BOILER WITH FGD • MBG-FIRED BOILER
	SUPERHEATER SELECTION	• NO SUPERHEAT, USE SATURATED STEAM IN DRIVERS • COAL-FIRED SUPERHEATER WITH FGD *• MBG-FIRED SUPERHEATER
AIR SEPARATION	CONFIGURATION	*• MAXIMUM PURITY O_2, GASEOUS PRODUCT • MINIMUM PURITY O_2, GASEOUS PRODUCT • MAXIMUM PURITY O_2, LIQUID PRODUCT • MINIMUM PURITY O_2, LIQUID PRODUCT
COAL FEED	SELECTION	*• AS MINED COAL • WASHED COAL • DEEP CLEANED COAL
WATER TREATMENT	SELECTION	• TREATMENT FOR RIVER DISCHARGE *• ZERO-LIQUID DISCHARGE TO RIVER

*Selected Alternative

2. Product Cost Sensitivity Analysis

Effects on product cost were analyzed for the sensitivity cases defined in Table II.C.2.

The results are summarized in Table II.C.3 for product price effects. The Table shows that:

- The greatest impact occurs when the economic factor is increased to 20%. This results in an increase of product price in constant 1980 dollars to $9.17 from the base case value of $6.64, an increase of 38.1%.
- The next most significant impact is due to service factor changes. At a 60% service factor, the product price increases by 23.3% to a value of $8.19. The increase accelerates as the service factor drops.
- The third most significant impact is the 50% coal cost increase, which raises the product price 18.3% to $7.86.
- A close fourth is the 50% increase in operating costs, producing a 15.9% increase in product price to $7.70.
- A capital costs increase of 25% has only half the impact of the operating cost increase. The resulting product price is $7.21, an 8.6% increase over the base case.

Small impacts of 6% or less are obtained from the variations due to sale of sulfur, changes in the design/construction period, changes in operating life, reduction of sulfur in the product gas, and variation in product gas pressure.

One result deserves special comment. The extension of operating life has opposite effects on UAE and product price. The reason is that price escalation in the extended years is so great that 1980 prices have to drop to keep revenues from exceeding cost. By contrast, the UAE must rise to account for the increased present value of O&M costs.

TABLE II.C.2. SENSITIVITY ANALYSIS APPLIED TO COST OF GAS

		INCREMENT
1.	COAL COST	+ 50%
2.	CAPITAL COST VARIATION	+ 25%
3.	OPERATING COSTS	+ 50%
4.	SERVICE FACTORS (BASE CASE = 90%)	80%, 70%, 60%
5.	BYPRODUCT VALUE	SEE TABLE BELOW
6.	DESIGN/CONSTRUCTION PERIOD PER MODULE	± 1 YEAR
7.	OPERATING LIFE YEARS	+ 5, +10
8.	SULFUR IN PRODUCT GAS	TO 1.0 PPM
9.	PRODUCT GAS PRESSURE	MAX = 800 psi MIN = 200 psi 1/
10.	ECONOMIC EVALUATION FACTOR	T.B.D.

BY-PRODUCT VALUES FOR SENSIVITITY ANALYSIS 2/

SULFUR, $/TON	70.00
SULFURIC ACID, $/TON	60.00
AMMONIA (ANHYDROUS), $/TON	130.00
NAPHTHA (120-320°F), $/GAL	0.80
LIGHT OIL (300-700°F), $/GAL	0.80
TAR (700°F), $/GAL	0.60
PHENOLS, $/GAL	0.75
COAL FINES, $/TON	80% OF ROM COAL COST
EXPORT POWER, ¢/kWh	SAME AS COST TO PLANT
METHANOL, ¢/GAL	35

1/ LOWEST PRACTICAL VALUE ABOVE 200 psi PERMITTED BY DESIGN CONSTRAINTS (CONTRACTOR TO RECOMMEND VALUE).

2/ EXCEPT FOR COAL FINES AND ELECTRIC POWER, ESCALATE BYPRODUCT VALUES AT SAME RATE AS COAL PRICES.

TABLE II.C.3. SUMMARY OF SENSITIVITY RESULTS ON PRODUCT PRICE

CASE	PRODUCT PRICE	VARIATION OF PRODUCT PRICE FROM BASE CASE	
	(1980$/MMBTU)	(1980 $/MMBTU)	(%)
BASE CASE (90% Service Factor)	6.64	0	0
COAL COST INCREASE			
BY 50%	7.86	1.22	18.3
CAPITAL COST INCREASE			
BY 25%	7.21	.57	8.6
OPERATING COSTS INCREASE			
BY 50%	7.70	1.06	15.9
SERVICE FACTOR			
80%	7.03	.39	5.9
70%	7.53	.89	13.3
60%	8.19	1.55	23.3
SALE OF SULFUR BYPRODUCT			
AT $70/TON	6.43	-.21	-3.1
VARIATION IN DESIGN/ CONSTRUCTION PERIOD PER MODULE			
+ 1 YEAR	6.79	.15	2.3
- 1 YEAR	6.51	-.09	-2.0
VARIATION OF OPERATING LIFE			
+ 5 YEARS	6.40	-.24	-3.6
+10 YEARS	6.25	-.39	-5.9
REDUCE SULFUR IN PRODUCT			
GAS TO 1.0 PPS	6.81	.17	2.5
PRODUCT GAS PRESSURE			
(BASE CASE = 600 psi)			
200 psi	6.32	-.32	-4.9
800 psi	6.75	.11	1.6
ECONOMIC EVALUATION FACTOR			
(BASE CASE = 12%)			
8%	5.82	-.82	-12.3
16%	7.75	1.11	16.7
20%	9.17	2.53	38.1

D. ALTERNATE PRODUCTS ANALYSIS

The purpose of this analysis is to provide cost estimates for potential alternative products to aid in product mix and process technology decisions for the facilities. Designs were developed at two levels, preliminary and definitive. Preliminary designs and cost estimates were developed by factoring flows and cost versus capacity from representative systems in previously published designs. The definitive designs were prepared in accordance with the conceptual design methodology used for the MBG facility designs.

The preliminary designs were developed as "add-on" modules, i.e., as separate plants receiving MBG "over the fence," produced to TVA specifications. This approach was based on the assumption that alternate product production would function as a temporary load leveler while the demand for MBG grows to equal plant capacity. The product costs, however, are based on the assumption that the alternate product modules are operated at 90 percent of design capacity for 20 years, the life of the MBG module. The definitive design were developed as fully integrated plants. Three sets of cases were developed as follows:

I. Koppers-Totzek and Texaco Single Product Facilities

Koppers-Totzek	to methane	:	preliminary
Koppers-Totzek	to methanol	:	preliminary
Koppers-Totzek	to gasoline	:	preliminary
Koppers-Totzek	to hydrogen	:	preliminary
Texaco	to methane	:	preliminary
Texaco	to methanol	:	preliminary
Texaco	to gasoline	:	preliminary
Texaco	to hydrogen	:	preliminary

II. Lurgi Single Product Facilities

Lurgi	to methane	:	preliminary
Lurgi	to methanol	:	preliminary

III. Mixed Product Facilities

Koppers-Totzek and Texaco to MBG and methane : definitive

Koppers-Totzek to MBG and methane : definitive

The cost results for each set are summarized in Figure II.D.1. A detailed discussion of the designs and associated analyses and tradeoffs that led to specific process selections is presented in Appendix C.

The potential marketability of the alternate products is discussed in Section G below.

In every instance, the Texaco products are less costly than the Koppers-Totzek products. This is due to the considerably higher efficiency of the Texaco gasifier, as evidenced in the higher product yield. The higher product yield and lower operating cost of the Texaco gasifier more than compensate for its higher capital cost. The cost of methane from the Lurgi gasifier is about the same as methane from Texaco.

The cost of methane, methanol, and hydrogen per million BTU are approximately equal (hydrogen is somewhat higher for Koppers-Totzek) with gasoline being about 20% higher.

The Lurgi cases were developed to examine the potential economic benefit of taking advantage of the high methane yield of the Lurgi gasifier by producing the methane as a product and converting the remaining gas to methanol. The cost results show that the mixed methane/methanol case does indeed result in a lower product cost per million BTU. However, the economic value of the two-product alternative depends on relative market prices for the two products, assuming there is a market for both. The product competitive evaluation indicates that methanol market prices may range from the same as methane, in direct competition for clean boiler fuel, to higher than methane as a substitute for distillate, or even higher as a gasoline blending stock. In the latter two cases, the combined methane/methanol plant would show a clear economic advantage over a methane only facility.

Two combined SNG/MBG cases were examined; Koppers-Totzek gasification only, and mixed Koppers-Totzek and Texaco. The facility consists of

	METHANE		METHANOL		GASOLINE		HYDROGEN	
	KT	TEXACO	KT	TEXACO	KT	TEXACO	KT	TEXACO
PRODUCT YIELD (10^{12} BTU/YEAR)	76	84	79	89	61	79	75	95
PRICE								
$1980/MMBTU	8.03	7.63	8.08	7.54	11.21	9.04	8.94	7.61
$1980/GALLON	-	-	0.53	0.48	1.25	1.01	-	-
$1980/MSCF	8.03	7.63	-	-	-	-	2.90	2.47

	LURGI METHANE	LURGI METHANE-METHANOL	KOPPERS-TOTZEK MBG-METHANE INTEGRATED FACILITY	K-T/TEXACO MBG-METHANE INTEGRATED FACILITY
PRODUCT YIELD (10^{12} BTU/YEAR)				
MBG ANNUAL PRODUCT	-	-	45.04	51.45
METHANE ANNUAL PRODUCT	94.37	58.42	35.04	37.62
METHANOL ANNUAL PRODUCT	-	50.88	-	-
TOTAL	94.37	109.30	80.08	89.07
INTEGRATED FACILITY PRODUCT PRICE				
$1980/MMBTU	$7.69	$6.81	$8.02	$6.49

Figure II.D.1. Summary of Alternate Product Costs

four 5000 ton per day MBG modules feeding an upgrading plant producing MBG. In the first case, all four modules use Koppers-Totzek gasifiers. In the second case, the second, third, and fourth modules use Texaco gasifiers. The design guidelines are as follows:

- The first two facility modules must be designed to produce 100% MBG, 100% SNG, or a mixture of both.
- Any of the four facility modules must be capable of feeding the MBG Upgrading Plant.
- The MBG Upgrading Plant shall be integrated with the remainder of the Coal Gasification Facility, rather than being designed as an add-on plant.

The cost figures show a clear economic advantage to incorporating the Texaco gasifiers. As described earlier, this results from the higher efficiency and lower operating cost of the Texaco gasifier, which more than compensates for its higher capital cost. The fraction of annual BTU's going to MBG or methane is slightly different in the two cases, reflecting small differences in gas composition and gas stream conditions.

There is a capital cost "penalty" associated with the desired flexibility to use any of the four modules with the upgrading plant and to make up to 100% SNG. Specifically, the Acid Gas Removal Systems in all four modules are specified to achieve deep sulfur removal (to avoid damaging catalysts in the upgrading units), although only two modules would supply MBG for upgrading at any one time.

E. SCHEDULING ANALYSIS

1. Milestones

The program development methodology encompasses the establishment of a specific set of time-structured elements scheduled for completion at predesignated dates. To facilitate effective program management of system development, and to ensure management review of program status, a set of objective-oriented milestones have been established. These milestones include:

(1) Program Requirements Review (PRR)
(2) Preliminary Design Review (PDR)
(3) Critical Design Review (CDR)
(4) Operational Readiness Review (ORR)
(5) Start of Commercial Operations (SCO)

a. Program Requirements Review (PRR)

The PRR will be a vehicle for review and approval of the complete systems requirements for all functions to be performed by the coal gasification facility. It will occur four months from the start date and will present for program management approval a complete Functional Description, a Test Plan and a list of system deliverables related to both the total system and individual module development.

b. Preliminary Design Review (PDR)

The PDR will occur twelve months after the start date and at this time program management will review the complete system and subsystem designs. All system and subsystem specifications will be completed in draft form for review. The Test Requirements will be approved at this review. Construction of well defined systems such as coal handling, solids disposal, plant power, general facilities may begin shortly after the PDR and prior to the critical design review.

c. Critical Design Review (CDR)

Twenty months from the start date, a CDR will be held to approve all specifications. The drafts presented at the PDR will be revised as necessary to meet program development requirements, and

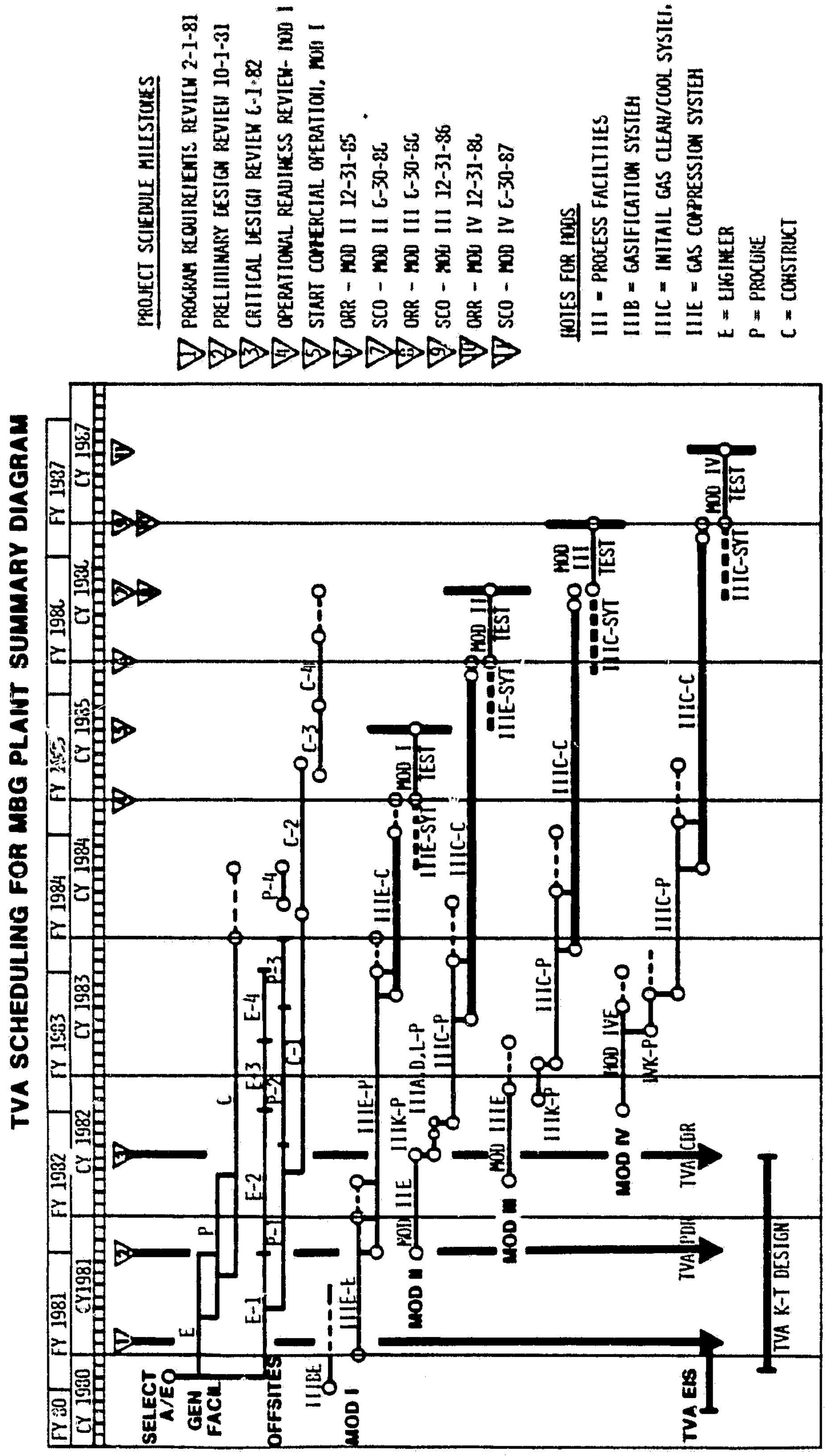


Figure II.E.1. Master Schedule

specifications will be defined to the subsystem level. The final version of system, subsystem, and test specifications will be approved at the CDR. Approval of the CDR will mark the initiation of major construction activity for all systems not already started. The final designs and specifications provide the necessary guidance and instructions for remaining program development activities.

d. Operational Readiness Review (ORR)

This milestone is the fourth to be reached and occurs approximately 51 months from the program start date. The objective of the ORR is to review completed system acceptance test results to determine operational readiness of each module. Complete program documentation review is also performed during this review. Following the ORR a six month period of module testing will commence.

e. Start of Commercial Operation (SCO)

The SCO constitutes the final phase of program development. The results of module testing and evaluation will be reviewed and commercial operation of each module will commence. Total facility management, operation, maintenance, and logistic support will proceed in accordance with the conceptualized standard operating procedures, facility operating instruction, system safety plans, and quality assurance requirements.

2. Master Schedule

The major program development activities and their time phased relationship to each of the four system modules is shown in the Coal Gasification Facility Project Master Schedule. Specific major activities include engineering procurement, construction, and testing. Also included are the program milestone and their associated dates.

3. Logic Nets

The following schedule logic nets have been prepared:

(1) Summary Diagram. This shows project milestones and an overview of the engineering, procurement, construction, and testing of the total facility.

(2) Module I General Facilities and Offsite Systems. Engineering, procurement, construction, and test phases are shown.

(3) Modules I-IV. Individual nets are given for the engineering through test cycle.

(4) Management and Planning Functions. This net addresses contract monitoring selection of A/Es, and other management and planning functions.

(5) Design, Procurement, Construction. The major activities in designing, procuring, and constructing the facility are scheduled. There are two major concerns with regard to the overall plan:

(a) It is important to insure that all possible early construction is completed before the last equipment arrives, i.e. maintain overlap between delivery and construction.

(b) Gasification, gas cleanup/cooling, and acid gas removal are time-consuming to test, and will require a relatively long time before attaining design scale equilibrium.

Other critical schedule factors were identified:

(1) Module I - General facilities and offsite systems. There is a need for systems testing for cost handling, solids disposal, and byproduct processing beyond what is shown. This testing will have to be proportionately more than for the plant power system.

(2) Module I - Engineer/procure/construct/test. Gasification is the most critical function, particularly when needed testing is added.

(3) Module II, III, and IV. The Gas Cleanup/Cooling system is the most critical. The systems testing requirement may not afford time for slippage or adequate testing. Procurement and construction might be started earlier to base the tight schedule.

F. PRODUCT COMPETITIVE EVALUATION

1. Introduction and Background

The purpose of this analysis is to provide a preliminary assessment of the potential competitiveness of the candidate products of the TVA coal gasification plant. The analysis is based on projected national average prices for competing fuels, and comparisons of these prices with projected product costs for the gasification plant. This analysis does not address the potential size of the market. Additionally, transportation and distribution costs of the gasification products are not included in the comparisons.

2. Estimated Gasification Plant Product Prices

The estimated product prices for gasification plant products are shown in Figure II.F.1. The prices are expressed in 1980 dollars and represent the price in constant 1980 dollars that would recover the cost of service of the plant. Thus, the corresponding nominal or current price would increase in proportion to the general rate of inflation.

3. Selection of Competing Fuels

Figure II.F.2 summarizes the rationale for the selection of fuels with which the gasification plant products might compete. Medium BTU gas (MBG) would compete with other industrial boiler fuels. Methane would compete with other sources of new gas supplies for gas utilities. The highest price a gas utility would pay for new gas would be determined in part by the highest priced competing fuel. Distillate for space heating is by far the most significant highly priced fuel competing with natural gas.

Methanol has a wide variety of uses. It can compete with distillate and natural gas as a boiler fuel, turbine fuel and chemical feedstock. Additionally, it can be blended into gasoline or used as a pure motor fuel. Use of methanol for all these applications is expected to grow dramatically over the next ten years. Methanol can also be converted to gasoline, which is the basis for the gasoline alternate product.

	ALTERNATE PRODUCTS			
GASIFIER	MBG	METHANE	METHANOL	GASOLINE
KOPPERS-TOTZEK	6.64	8.03	8.08	11.21
TEXACO	5.00	7.63	7.54	9.04
BABCOCK & WILCOX	6.39	--	--	--
SLAGGING LURGI	4.31	--	--	--
LURGI	5.44	7.69	--	--

Figure II.F.1. Gasification Product Costs, 1980 $/MMBTU

GASIFICATION PLANT PRODUCT	COMPETING FUEL	RATIONALE
MBG	INDUSTRIAL RESIDUAL FUEL OIL	COMPETE FOR BOILER FUEL
	INDUSTRIAL DISTILLATE	COMPETE FOR BOILER FUEL
METHANE	NEW NATURAL GAS	INCREMENTAL COST OF GAS SUPPLY
	RESIDENTIAL DISTILLATE	COMPETE FOR SPACE HEATING
	COMMERCIAL DISTILLATE	COMPETE FOR SPACE HEATING
METHANOL	INDUSTRIAL DISTILLATE	COMPETE FOR BOILER AND TURBINE FUEL
	NEW NATURAL GAS	COMPETE FOR BOILER FUEL AND CHEMICAL FEED
	WHOLESALE GASOLINE	COMPETE FOR GASOHOL BLENDING STOCK OR MOTOR FUEL
GASOLINE	WHOLESALE GASOLINE	

Figure II.F.2. Selection of Competing Fuels

4. Projected Prices for Competing Fuels

Prices are taken from the Energy Information Administration 1979 Annual Report to Congress, Vol. 3, DOE/E1A-0173(79)13.

World oil prices range from no real increase in the low scenario to a doubling of the real price in the high scenario over the operating life of the plant. Fuel oil, distillate and gasoline have similar ranges. Power cost variations and real growth are very low due to the high portion of costs represented by capital recovery and to the large existing capital base relative to projected growth. The "wholesale gasoline" prices are taken as 90% of retail, based on recent EIA data showing wholesale gasoline at 88% to 91% of retail.

New natural gas real price increases are projected to range from 25% to over 300% over the operating life of the plant.

5. Comparison of Gasification Plant Product Prices with Competing Products

The prices of gasification plant products are compared with high and low projected prices for competing fuels in Figures II.F.3, .4, and .5. All prices are in 1980 dollars. World crude price is also displayed in Figure II.F.3, for reference. For the sale of clarity, only the Koppers-Totzek gasification plant product prices are displayed. Other prices from Figure II.F.1 are readily compared, however, since the 1980 dollar prices for gasification plant products are simply horizontal lines on the graphs. No adjustments have been made for transportation or distribution costs of the gasification plant products, except for residential distillate. In this case $2/MMBTU was subtracted from the cost of residential distillate to reflect the cost differential between residential and well head gas (estimate obtained from EIA).

As can be seen from Figure II.F.3, MBG compares favorably with the mid-range price of competing fuels and should be highly competitive as an industrial boiler fuel.

As shown in Figure II.F.4, gasification plant methane can compete favorably only with the higher priced sources of new gas and distillate for space heating. Thus, as natural gas supplies decline,

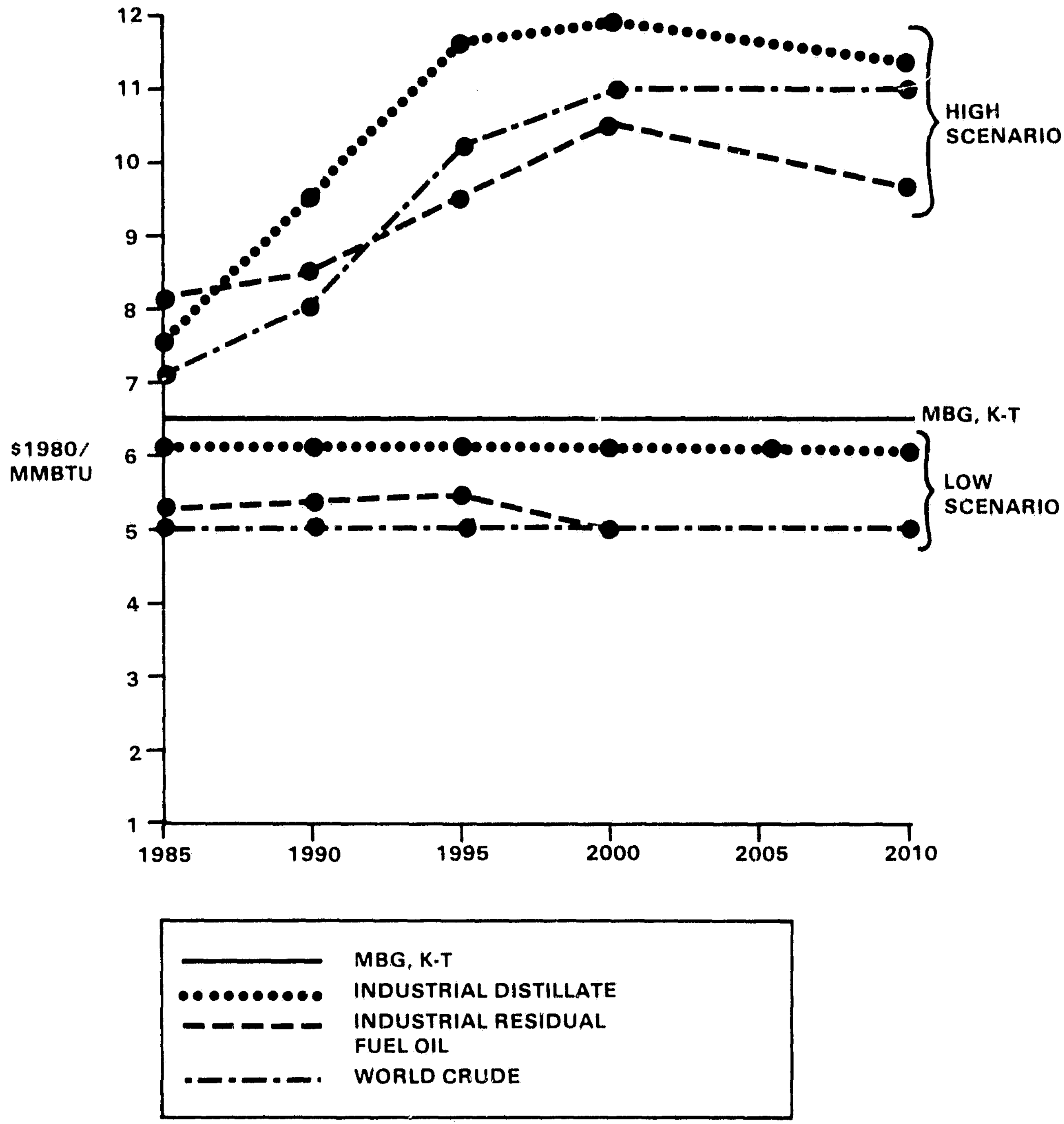
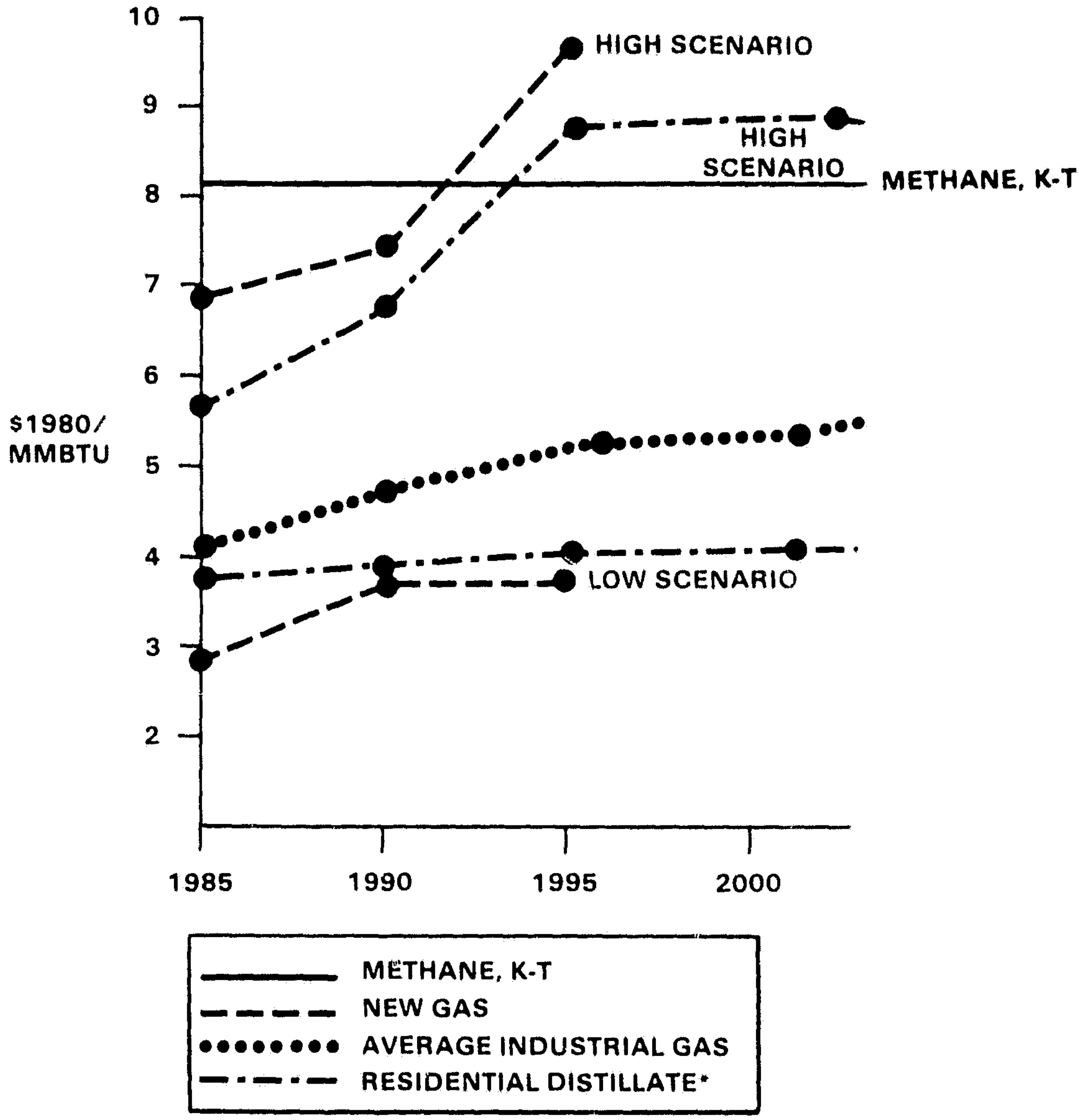


Figure II.F.3. Price Comparisons for MBG



*$2/MMBTU SUBTRACTED TO ADJUST FOR WELLHEAD DIFFERENTIAL WITH RESIDENTIAL GAS.

Figure II.F.4. Price Comparisons for Methane

coal derived methane may be a competitive fuel in the space heating market.

Methanol and gasoline are compared in Figure II.F.5. Both products appear to be highly competitive with the mid-range forecasts. A significant point is illustrated by the figure; to the extent that methanol can be used as an above-average quality gasoline blending stock, it is always more economic to use methanol for blending than to convert it to gasoline. In other words, coal can be converted to gasoline more cheaply by blending methanol than by converting methanol to gasoline.

In summary, MBG, methanol, and gasoline appear to be highly competitive. Methane is only marginally competitive with the highest price competing fuels in the high-scenario forecast. Methanol is the most competitive alternate fuel, and is attractive as a gasoline blending stock.

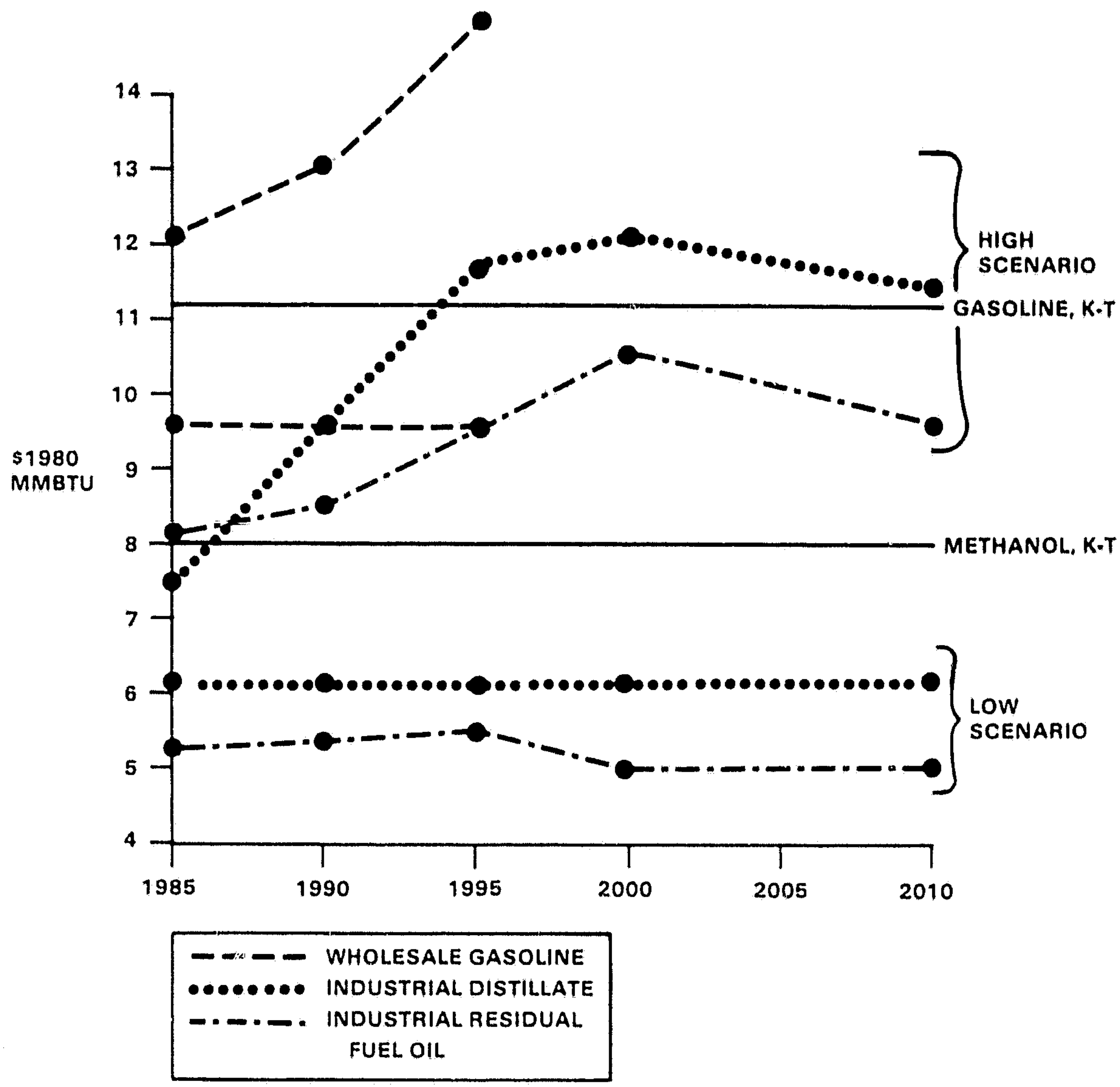


Figure II.F.5. Price Comparisons for Methanol and Gasoline

G. CRITICAL TECHNOLOGY ASSESSMENT

The process and equipment requirements for coal gasification have been reviewed and an assessment of the areas of critical technology made. Some fifty-five items and issues have been identified as potential areas for development work. These were evaluated based on the impacts given in Table II.G.1. Further, these items and issues were prioritized for purposes of recommendation for development work and an associated development work plan.

Generally, the net benefit from major development efforts in the process industries is derived from broad application of new developments throughout the industry rather than from a single plant application. However, the evaluations completed in this work were arrived at those which would have maximum application in the TVA facility. Thus, the development programs recommended here are limited to those items associated with entrained gasifier plants such as K-T, Texaco and B&W. No consideration is given to other critical areas which might apply exclusively to such plants as Lurgi or BGC/Lurgi as they are not believed to be viable candidates for the TVA project.

The most significant critical technology items are found to relate to the gasifier itself, the gasifier reactant feed system, and the recovery of heat from product gases. Benefits from these potential improvements take the form of improved service factors or improved efficiency. Up to 75 million dollars in development and capital costs are justified in improving efficiency by one percent in a single 20,000 TPD plant; up to 18 million dollars are justified in improving the service factor by one percent.

It is recommended that any coal gasification technology development program at MSFC have a large commitment to improving gasifier refractory improvement. Improvements in this area could benefit both service factors and efficiency. Excessive downtime to replace or repair refractory is costly. Avoiding refractory problems by operating with a solidified slag coating in the reactor requires either capital investment to imbed steam coils in the refractory or production of low pressure steam of marginal value in reactor jackets. A program to improve refractory is believed to have the greatest potential for major direct application in the TVA plant.

TABLE II.G.1

IMPACT OF CRITICAL TECHNOLOGY ISSUES:

1. DESIGN - Data is required to design the plant to meet specifications or improve plant design optimization.

2. COST REDUCTION -

    a. Initial Capital Cost - Technology development will reduce plant initial capital cost.

    b. Replacement Capital Cost - Technology development will reduce the cost per year of replacement capital items.

    c. Maintenance Costs - Technology development will reduce annual plant maintenance costs.

3. OPERABILITY -

    a. Product Specs - Technology development is required to ensure that the plant meets product specs.

    b. Emission Specs - Technology development is required to ensure that the plant meets emission specifications.

    c. On-Stream Time - Technology development will improve on-stream time.

    d. Efficiency - Technology development will improve plant energy efficiency.

    e. Safety - Technology development will improve plant safety.

In order to establish additional potential for a major improvement in coal gasification technology, it is recommended that a large test facility be established suitable for developmental and test work on prototype heat recovery and gas cleanup equipment. The capacity of this facility should be equivalent to several hundred tons per day coal feed in order to demonstrate flow similarities with full scale equipment. The recommended approach to supplying this type of facility is to establish a slipstream or dedicated gasifier in conjunction with the TVA plant. If this proves not to be feasible, a test facility based on oil gasification should be established at MSFC. Oil gasification with injection of ash and other appropriate substances is preferred over coal in order to facilitate long term (months) testing and eliminate coal handling as a concern. Recycle of gas product would be used to minimize oil consumption and product disposal problems and at the same time provide a test facility for gas compression prototype seal testing.

Depending upon the final size selected, it is anticipated that the installation of a major test facility such as this will cost on the order of 20 to 50 million dollars. A staff of 30 to 40 persons would be required to support such a facility. If such a facility is built, it is recommended that a commercial supplier such as Texaco or Shell be contracted to furnish the design for the basic gasifier system.

Additional smaller programs and recommendations are discussed in Chapter XII of Volume II. These programs include such items as slurry pump, materials of construction, and chemical/physical phenomena associated with down stream processing.